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Monitoring of cargo transport in urban areas using GPS/EGNOS technologies as part of the safety system

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Abstract

Safety in the transport of goods in cities much depends on the choice of route and monitoring of heavy vehicles in urban areas. When a passage route has been selected, the transport firm must have control over the driver's performance. This article presents results of research into the accuracy of the position determination by the GPS/EGNOS system in highly urbanized areas with continuous building lines. The results are compared to those obtained in open field areas.

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1. Introduction

The dynamic development of public transport has called for its monitoring, management and optimization. A spectrum of arrangements and measurement methods are in use to fulfill these functions. Navigational satellite systems, an essential component of traffic monitoring and management systems commonly in use today, provide satisfactory accuracy. In densely built up urban areas, however, the availability of navigational satellite signals may be limited. This is due to the celestial sphere being partly obscured by tall buildings, the multipath effect of the signal caused by reflections from buildings and the ground, and inference from other sources of electromagnetic radiation (Rao B.R.K., Sarma A.D.& Kumar Y.T. 2006). All these factors cause the signal to fade away or degrade

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the accuracy of vehicle position coordinates determination, which results in the disruption of tracking, wrong alterations of the route or wrong prompts to do so. This often lengthens passage time and track covered, adversely affecting the cost-effectiveness of road transport.

Today, the GPS system continues to be a navigational aid of greatest availability (Specht C. 1997) and is, in fact, commonly employed by road users. The EGNOS system superimposes the GPS and GLONASS systems, which allows enhancement of the accuracy, availability, reliability and continuity of position determination. The accuracy of position obtained by the GPS/EGNOS system is about 3-5 m (at confidence level P = 0.95) and depends on a number of factors. Two factors of principal importance are the configuration of observable satellites (their number and mutual location in space) and the antenna position, affecting the number of tracked satellites and the effect of multipath.

This article examines the accuracy of position determination by a GPS/EGNOS system in an urban densely built up area and comparing the results with positions obtained in an open area.

2. Research stations

The tests have been made at three measuring stations, which represent different measuring settings. All three are located within Szczecin perimeter:

- measuring point *Glinki (A),* located in an open area without buildings, with grassy ground, offering good conditions of signal reception;
- measuring point *Bolesław Śmiały* Street *(B),* located in a narrow street with rows of adjacent buildings about 25 metres high. The antenna was installed on a car roof (at height of 2 metres): the celestial sphere was considerably covered by buildings, so possibilities of multipath effect existed there;
- measuring point *AM Szczecin(C),* located on an antenna platform, about 35 metres above the ground, overlooking the roofs of neighbouring buildings. The antenna could see the whole celestial sphere. although there were chances for reflections from neighbouring roofs and slight shades from radio antennas at a distance of 2 to 4 metres.

The selected measuring points are located in urban conditions characteristic of most measurements performed by GPS/EGNOS receivers. The measuring point Glinki is a good measuring location, typical of field measurements. The one at AM Szczecin (Maritime University) well represents conditions of measurements performed in monitoring stations and by public institutions (land surveyors, police, vehicle fleet managers), while the point at Bolesław Śmiały Street is a typical location for measurements carried out in city traffic. The deployment of measuring points in the field is depicted in Figure 1:

Fig. 1. Szczecin – measuring points: A – Glinki, B – AM Szczecin, C – Bolesław Śmiały Street. Source: Google

3. The research method

The position determination accuracy obtained by the GPS/EGNOS system has been analyzed depending on measurement location and conditions. We have performed parallel measurements using three identical CSI-made MiniMAX receivers. The use of the same type receivers (with the same software) for investigations is aimed to eliminate possible errors resulting from the use of various type receivers for measurements. The receivers have been handled using PocketMax PC_Ver.2.0 software, enabling the choice of recorded data from MiniMAX receivers by PC computers. Three measurement sessions were executed in autumn. All measurement series were performed at an identical frequency of 1 Hz. For each series of measurements the following parameters were recorded:

- GPGGA – moment, latitude and longitude, height, HDOP (Horizontal Dilution Of Precision), number of satellites tracked, correction age;
- GPGGL – latitude and longitude, moment, status;
- GPGSA – position mode (2D/3D), (M/A), PDOP (Position Dilution Of Precision), HDOP, VDOP Vertical Dilution Of Precision).

The recorded navigational data have been used for calculations as per these formulas (Hsu D.Y. 1999, GPS POSITIONING GUIDE 1995, Mertikas S. 1994):

- mean value

- radius of error circle (P = 95%)

- parameters of the error ellipse (a, b,) (P = 95%)

- variance

- covariance

4. Description and analysis of the results

The data collected during measurement sessions underwent preliminary and statistical processing (Banachowicz A., Bober R., Banachowicz G., Wolski A. 2005). We have calculated the following parameters for each measuring point and session:

- mean latitude ( ),
- mean longitude ( ),
- mean antenna height (H),
- radius of error circle (M) (P = 95%),
- parameters of the error ellipse (a, b,) (P = 95%).

The results are given in Table 1:

Table 1. The measurement results from measurement sessions in three locations

	Glinki (A)	Akademia Morska (B)	Bolesław Śmiały (C)
		Session I	
[deg., min., sec.]	53° 30' 16.66"	53° 25' 44.93"	53° 25' 59.74"
[deg., min., sec.]	014° 36' 14.86"	014° 33' 49.19"	014° 32' 13.51"
H [m]	81.86	44.95	44.29
M (95%) [m]	2.57	1.12	33.26
a [m]	1.4797	0.5394	18.8955
b [m]	0.1343	0.3650	3.5119
[°]	22.2	16.7	31.3
		Session II	
[deg., min., sec.]	53° 30' 16.60"	53° 25' 44.93"	53° 26' 00.18"
[deg., min.. sec.]	014° 36' 14.81"	014° 33' 49.15"	014° 32' 13.97"
H [m]	82.54	44.88	8.32
M (95%) [m]	1.16	0.72	58.72
a [m]	0.6161	0.3730	33.8441
b [m]	0.2772	0.1873	2.3976
[°]	11.6	60.3	19.7
		Session III	
[deg., min., sec.]	53° 30' 16.60"	53° 25' 44.87"	53° 25' 59.86"
[deg., min., sec.]	014° 36' 14.81"	014° 33' 49.15"	014° 32' 13.76"
H [m]	82.30	44.87	24.91
M (95%) [m]	1.16	1.45	33.37
a [m]	0.5911	0.7625	18.8818
b [m]	0.3469	0.3592	3.9111
[°]	4.3	33.4	20.5

Source: authors' study

Figures 2, 3 and 4 present a scatter plot and the dispersion of indicated points in measurement series in the horizontal plane, locally tangent to the measuring point. The best concentration can be observed in Fig. 2 illustrating measurements at the Glinki point (session III). The error circle at the significance level P = 95% was M = 1.16 m, semi-axes of the error ellipse (P = 95%): a = 0.5911 m, b = 0.3469 m. A small difference between the error ellipse semi-axes means there is a weak correlation of latitude and longitude measurements. Note that the measurements were carried out in good field conditions, that is the celestial sphere was not obscured. For this reason, the results display high accuracy and stability, without blunders.

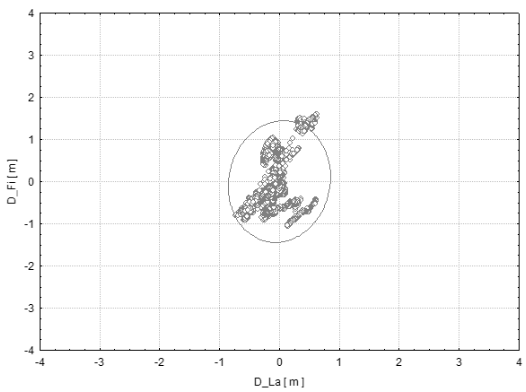

Fig. 2. A scatter plot at the Glinki measuring point (session III).

The next diagram (Fig. 3) presents a position scatter obtained on the roof of the Maritime University of Szczecin (*Akademia Morska*). In this location measurements are also relatively accurate (error circle was M = 1.45 m, error ellipse semi-axes: a = 0.7625 m, b = 0.3592 m). The data results are also stable, but better correlated than those at the Glinki point.

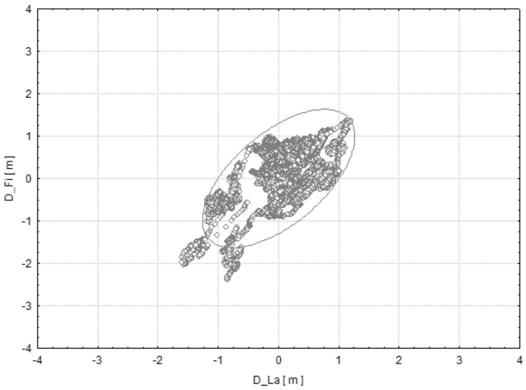

Fig. 3. A scatter plot at the Akademia Morska measuring point (session III).

Unlike the two previous measurements, those performed at *Bolesław Śmiały Street* (Fig. 4) are characterized by low stability (characteristic position dragging is visible in the diagram), due to the multipath of the signal and the changes of the geometric horizontal coefficient of the system, as discussed further. Consequently, accuracy parameters of position are approximately 30 times worse than in good measurement conditions (error circle was M = 33.37 m, error ellipse semi-axes: a = 18.8818 m, b = 3.9111 m).

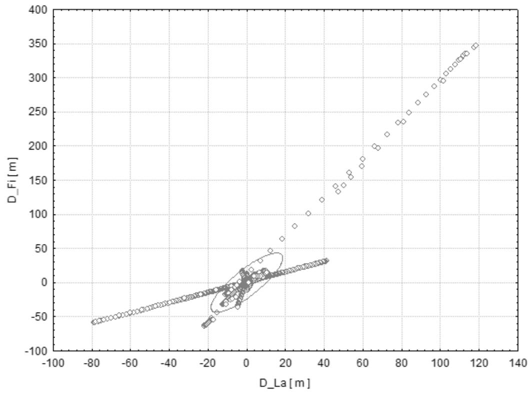

Fig. 4. A scatter plot at Bolesław Śmiały Street measuring point (session III).

The following diagrams (Figures 5, 6, 7) show varied deviations of an instantaneous latitude from the mean value in a series. Figure 5 illustrates the situation at the Glinki point. We can observe that the oscillations are slight, ranging from 1.0 m to 1.5 m.

Fig. 5. Deviations of instantaneous latitude from the mean value obtained at the Glinki measuring point (session III).

In the case of the measuring point on the building of the Maritime University of Szczecin (Fig. 6) variations are slightly larger and range from 2.5 m to 1.8 m. In both of the above cases there are no visible 'peaks' of position.

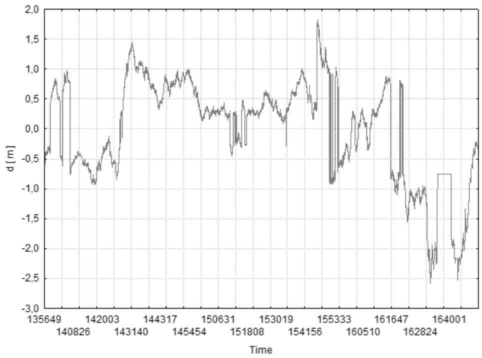

Fig. 6. Deviations of instantaneous latitude from the mean value obtained at the Akademia Morska measuring point (session III).

The situation and corresponding diagram are different when it comes to measurements in typical city conditions (Fig.7). The plot features outstanding leaps of latitude (and positions) in the form of peaks that translate into more than 300 metres of distance.

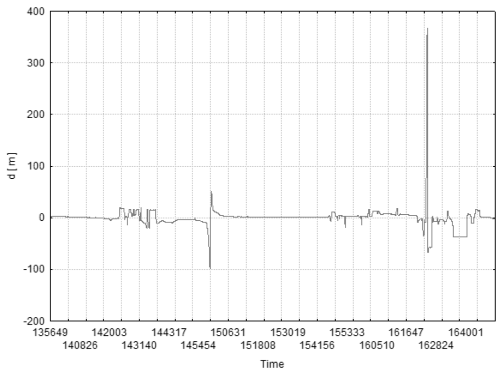

Fig. 7. Deviations of instantaneous latitude from the mean value obtained at the Bolesław Śmiały Street measuring point (session III).

As mentioned before, the positioning accuracy depends on satellite configuration, characterized by the so called geometric dilution of precision. In this case we are concerned with the position accuracy on the Earth's surface, which means the horizontal coefficient (HDOP) is taken into account. Figures 8, 9 and 10 present the variation of HDOP at each measuring point.

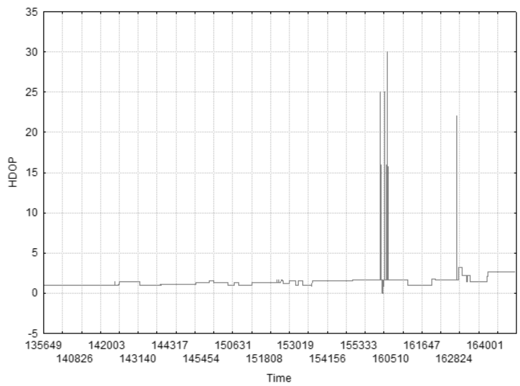

Fig. 8. HDOP coefficient for the Glinki measuring point (session III).

Measurements at Glinki are characterized by a low HDOP (Fig. 8), ranging from 1 to 3, although occasionally it jumps to values around 30. The peaks may be due to instantaneous disturbances of the signal or insufficient number of satellites taken for position calculations.

Similarly, at the measuring point *Akademia Morska* (Fig. 9), HDOP oscillates between 0.8 and 2.2, which proves the navigational signal reception is stable and sufficient number of satellites are available.

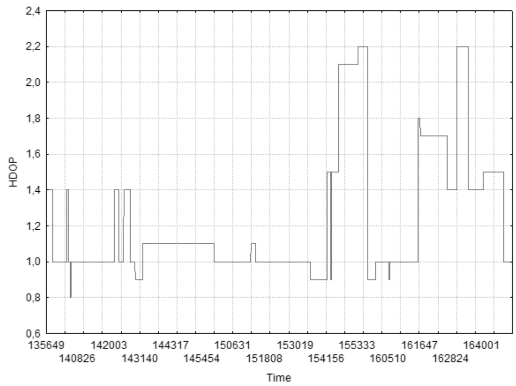

Fig. 9. HDOP coefficient for the Akademia Morska measuring point (session III).

The situation is much worse in the third measuring point in Bolesław Śmiały Street (Fig. 10). Due to the scale of the drawing it is difficult to determine HDOP during correct reception of the signal (it was a one digit value). The coefficient peaks sharply, however, when inferences occur, reaching values ranging from 100 to 1000, which makes it impossible to determine a correct position at the corresponding time intervals.

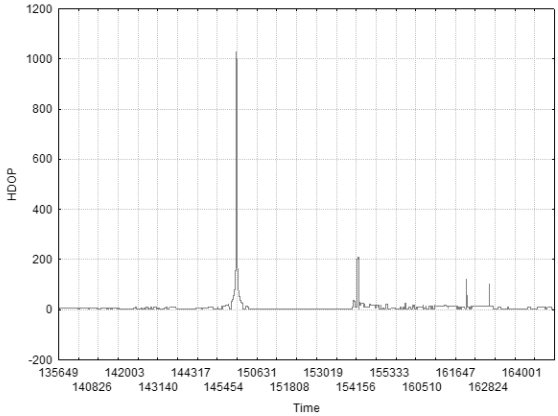

Fig. 10. HDOP coefficient for the Bolesław Śmiały Street measuring point (session III).

The data contained in Table 1 and the graphic illustrations of the results in Figures 2 – 10 imply that in good measuring conditions, when the celestial sphere is open, the accuracy and stability of GPS/EGNOS system measurements are high. On the other hand, in urban conditions with continuous lines of buildings on both street sides, the accuracy sharply decreases and may turn out to be insufficient for the determination of the vehicle's position within its traffic lane. Additional difficulties, such as a fading signal or too low an HDOP may occur.

4. Conclusion

The demonstrated results of the investigation of the accuracy and availability of the GPS/EGNOS system show that in practice it cannot be employed as the only system of continuous vehicle monitoring in urban areas. Due to the presence of radar shade in street 'canyons' and multiple reflections of the signal from buildings, the system should be supported by another system operating at periods when the correct satellite signal is not available. This may be an inertial system mounted on vehicles or a network of local pseudolites (pseudo satellites), a signal from which is received by GPS receivers. The extended GPS service using pseudolites presently finds applications in IBLS – Integrity Beacon Landing System, and in marine piloting systems (Basic Guide to Advanced Navigation. 2010, O'Driscoll C., Borio D., Fortuny J. 2011). Previously pseudolites were used in precise geodesy.

A comparative analysis of data shows that at the locations with similar reception conditions, free from multipath effect of the signal and confined celestial sphere (Glinki, AM Szczecin), deviations from the mean position are similar and do not exceed 2.5 metres. Similar results have been obtained on a fairway or open water area (Banachowicz A., Bober R., Banachowicz G., Wolski A. 2005). On the other hand, in a densely built up area (location Bolesław Śmiały Street) values of maximum deviations reach as far as 380 m. An assessment of the HDOP leads to the conclusion that at Bolesław Śmiały Street this coefficient at short time intervals has very large values reaching 1000, which considerably decreases the position accuracy.

The research has also shown that the accuracy of the position obtained from a GPS/EGNOS system depends on the antenna location, as this strictly relates to the number of observed satellites. If the receiver antenna observed the whole celestial sphere (*Glinki, AM Szczecin*), the position determination accuracy was M= 0.72- 2.57 m. When the receiver worked in a densely built up area of continuous lines of buildings (*Bolesław Śmiały Street*). then the accuracy was visibly lower (M=33.26-58.72 m). The data recordings featured very short but large oscillations of the HDOP coefficient that could not be explained by changes in satellite configuration. Besides, signals from EGNOS satellites were disappearing for substantial periods of time during the measurements.

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